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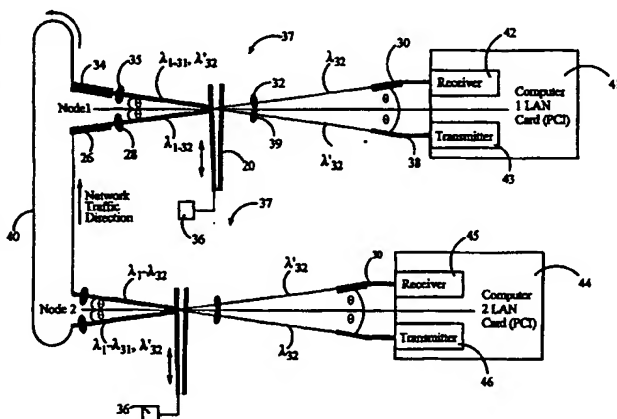
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(54) Title: **RECONFIGURABLE ADD/DROP MULTIPLEXER FOR FIBER OPTIC NETWORKS**



(57) Abstract: A reconfigurable add/drop multiplexer (100, 150) for use in an optical communications network includes an input optical waveguide (118, 162) propagating a multi-channel optical signal and a receiver optical waveguide (120, 170) optically aligned with the input waveguide. A transmission filter (106, 164) is in optical communication between the input optical waveguide and the receiver optical waveguide (120, 170) with the transmission filter being tunable to drop a select channel to the receiver optical waveguide (120, 170) and to reflect the remaining channels of the multi-channel optical signal. A retransmission waveguide (118, 162) is in optical communication with the transmission filter to receive the reflected remaining channels. A second receiver waveguide (130, 174) is in optical communication with the receiver waveguide (120, 170). A selectively reflective apparatus

(108, 168) is in optical communication between the receiver optical waveguide and the second receiver optical waveguide for selectively reflecting the dropped channel or transmitting the dropped channel to the second receiver waveguide. A second retransmission waveguide (130, 182) is in optical communication with the selectively reflective means receives a reflected optical signal. A method of dropping a select channel of a multi-channel optical signal propagated along a main optical waveguide without loss of data includes directing the multi-channel optical signal from the main optical waveguide to an input waveguide. The receiver waveguide is optically aligned with the input waveguide. A tunable transmission filter is provided in optical communication between the input and receiver waveguides. The transmission filter is tuned to drop a select channel to the receiver optical waveguide and to reflect the remaining channels of the multi-channel optical signal to a retransmission optical waveguide in optical communication with the main optical fiber. All dropped channels are reflected for repropagation along the main optical waveguide while the tunable transmission filter is tuned between first and second select channels. The transmission filter (106, 164) may be a wedged-etalon having a cavity that varies uniformly in width between a widest operative end and a narrowest operative end along a filtering axis in optical communication between the input and receiver waveguides. An actuator (107) moves the wedged-etalon out to select positions between the widest and narrowest operative ends to drop a select channel.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

RECONFIGURABLE ADD/DROP MULTIPLEXER FOR FIBER OPTIC NETWORKS

BACKGROUND OF THE INVENTION

Technical Field

The present invention is directed to fiber optic communications, and more particularly
5 to a reconfigurable add/drop multiplexer and method for changing between dropped channels
of a multi-channel optical signal without data loss for use in fiber optic networks.

Background Art

In current fiber optic networks, as many as 40 different channels are multiplexed on a
10 single fiber, each channel or data stream being at a different wavelength. Channel densities of
80 or higher are on the horizon. For effective communication, it is necessary to be able to
drop and add channels from such multichannel optical signals. For example, for two or more
computers at access points on an optical network to communicate, they must operate at the
same wavelength. However, many different wavelengths are present on the fiber that forms
15 the backbone of a network at any given time. To choose the channel of interest which occurs
at a particular wavelength, each node in the network must have the capability of receiving
only the channel of interest and transmitting at the same wavelength of the received channel
while passing other channels along the fiber backbone unaffected.

One current practice is to use fiber Bragg gratings that are wavelength tunable (by
20 physically stretching the fiber) to choose the wavelength of interest. Whatever device is used
at the node should have high efficiency, be capable of handling high channel densities, and be
reconfigurable (wavelength tunable). The channel spacing of the fiber Bragg gratings (~ 0.8
nm or 1.6 nm) limits the number of wavelengths that can be placed on the network.

Another current practice is to use Fabry-Perot devices that are fiber coupled. In these
25 devices, the spacing between two highly-polished, mirrored fiber ends is varied to tune the
pass wavelength of the filter as shown in Figure 1. All other wavelengths are reflected from
the filter. The resolution of such a device can be quite high, but for present purposes, a

resolution from 0.05 -0.1 nm is sufficient. The drawback of fiber coupled Fabry-Perot devices is that they require the spacing between the mirrored fiber ends to be controlled to a high level of precision (~ 1 nm). This requires the use of precision piezoelectric actuators and highly engineered mounting mechanisms. One representative multi-wavelength add/drop multiplexer using a Fabry-Perot filter is disclosed in Koonen, U.S. Patent No. 5,751,456.

Henry, U.S. Patent No. 6,035,080, is directed to a reconfigurable add/drop multiplexer for adding and dropping a select channel by switching the light path through one of a set of fixed Bragg add/drop filters. The selection among add/drop filters is done by sliding a planar integrated optic chip containing the add/drop filters between input and output waveguides. A bypass path is intended to compensate for disruption in the multichannel optical signal as the chip slides. The bypass uses a thermo-optic switches to direct the multi-level optical signal to a bypass path independent of the Bragg filters. The structure of Henry is an integrated planar waveguide and expensive and very complicated to build. Furthermore, the bypass apparatus requires a phase shift in the input data stream to select a path between two paths of Mach-Zehnder interferometer, one path leading to the bypass and the other path leading to the filter. This is a complicated way of ensuring that the entire optical signal bypasses the filter and virtually no data bits are lost.

Bowen, U.S. Patent No. 5,128,798, teaches a tunable wedged-etalon filter which is tuned by controlling the position along the taper at which light is directed through the wedge by the use of an acoustooptical deflector. However, the structure disclosed in Bowen is not suitable for use as an add/drop multiplexer because there is no provision for repropagating channels of the multi-channel optical signal which are not dropped by the wedged-etalon. Moreover, Bowen does not address the desirability of minimizing data loss while tuning. In addition, the acoustooptical deflector may be sensitive to environmental factors such as temperature and humidity and it is therefore difficult to dependably direct the input beam to a desired select location along the tapered axis of the wedged-etalon. Acoustooptical deflectors are also known to produce aberrations in the wavefront of the diffracted beam giving rise to additional loss.

The present invention is intended to overcome one or more of the problems discussed above.

SUMMARY OF THE INVENTION

A first aspect of the invention is a reconfigurable add/drop multiplexer for use in an optical communications network including an input optical waveguide propagating a multi-channel optical signal and a receiver optical waveguide optically aligned with the input waveguide. A wedged-etalon having a cavity that varies uniformly in width between widest operative and narrowest operative ends along a filtering axis is in optical communication between the input and receive waveguides. An actuator is operatively associated with the wedged-etalon to move the wedged-etalon to select positions along the filtering axis to selectively drop a select channel of the multi-channel operative signal corresponding to the select position to the receiver waveguide. A collimating optic is preferably provided between the input waveguide and the wedged-etalon and a focusing optic is preferably provided between the receiver waveguide and the wedged-etalon. A retransmission waveguide may be provided in optical communication with the wedged-etalon to receive all of the channels but the select dropped channel reflected by the wedged-etalon. The input waveguide and the retransmission waveguide may be a single waveguide. Furthermore, each of the waveguides may be optical fibers. A transmission waveguide may be further included in optical communication with the retransmission waveguide with the transmission waveguide being located on a side of the wedged-etalon opposite the retransmission waveguide for directing a transmission channel at the select position corresponding to the dropped channel. An optical transmitter is coupled to the transmission waveguide and propagates a channel having a wavelength equivalent to that of the select dropped channel. A reflective optic may be provided along with an actuator for moving the reflective optic relative to the input and retransmission optical waveguides to reflect the multi-channel optical signal to the retransmission waveguide before the multi-channel optical signal strikes the wedged-etalon. Alternatively, a second receiver waveguide is optically aligned with the receiver waveguide. The reflective optic is located between the receiver optical waveguide and the second receiver optical waveguide and an actuator is provided for moving the reflective optic into an out of optical communication with the receiver optical waveguide, with the second receiver optical waveguide and the receiver optical waveguide being in optical communication when the

reflective optic is out of optical communication with the receiver optical waveguide. A second retransmission optical waveguide is in optical communication with the reflective optic to receive a reflected optical signal when the reflective optical waveguide is in optical communication with the receiver optical waveguide. The reflective optic may be a second
5 wedged-etalon identical to the first wedged-etalon, whereby with the first wedged-etalon at a select position and the second wedged-etalon at the same select position, a select channel is propagated to the second receiver optical waveguide.

A second aspect of the present invention is a method of dropping a select channel of a multi-channel optical signal propagated along a main optical waveguide. The multi-channel
10 optical signal is directed from the main optical waveguide to an input waveguide. A receiver waveguide is optically aligned with the input waveguide. A wedged-etalon having a cavity that varies uniformly in width between a widest operative and a narrowest operative end along a filtering axis is provided in optical communication between the input and receiver waveguides. The wedged-etalon and the optically aligned input and receiver waveguides are
15 moved relative to one another along the filtering axis to a select position so as to selectively drop a select channel of the multi-channel optical signal corresponding to the select position. The method may further include reflecting all the multi-channel optical signal except the dropped channel to a retransmission waveguide in optical communication with the main optical waveguide to repropagate this portion of the multi-channel optical signal to the main
20 optical waveguide. The input waveguide and the retransmission waveguide may be a single waveguide and each of the waveguides is preferably an optical fiber. The method may further include transmitting a channel of a wavelength equivalent to the dropped channel through the select position of the wedged-etalon into the retransmission waveguide. Another embodiment of the method includes reflecting all of the multi-channel optical signal to the retransmission
25 waveguide while moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another along the filtering axis between select positions. Alternatively, the method may include reflecting all of the dropped channels for repropagation along the main optical waveguide while moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another along the filtering axis between select
30 positions.

A third aspect of the present invention is a reconfigurable add/drop multiplexer for minimizing data loss during reconfiguration for use in optical communications network includes an input optical waveguide propagating a multi-channel optical signal and a receiver optical waveguide optically aligned with the input waveguide. A transmission filter is in optical communication between the input optical waveguide and the receiver optical waveguide. The transmission filter is tunable to drop a select channel to the receiver optical waveguide and to reflect the remaining channels of the multi-channel optical signal. A retransmission waveguide is in optical communication with the transmission filter to receive the reflected remaining channels. A second receiver waveguide is optically aligned with the receiver waveguide. A selectively reflective apparatus is in optical communication between the receiver optical waveguide and the second receiver optical waveguide for selectively reflecting the dropped channel or transmitting the dropped channel to the second optical receiver waveguide. A second retransmission waveguide is in optical communication with the selectively reflective apparatus to receive a reflected optical signal. A main optical waveguide may further be provided for propagating the multi-channel optical signal. In this configuration, a first optical circulator is provided in optical communication with the main optical waveguide and the input optical waveguide for directing the multi-channel optical signal to the input optical waveguide. The input optical waveguide and the retransmission optical waveguide are preferably a single waveguide and the optical circulator receives the reflected remaining channels and propagates them along the main optical waveguide. A second optical circulator may be provided in optical communication with the receiver waveguide and a second input waveguide for directing the dropped select channel to the second input waveguide. The second input waveguide is optically aligned with the second receiver waveguide. When the selectively reflective means reflects a dropped channel, the optical circulator receives the reflected dropped channel and directs the reflected dropped channel for repropagation along the main optical waveguide. Each optical waveguide is preferably an optical fiber. The transmission filter may be a wedged-etalon having a cavity that varies uniformly in width between a widest operative and a narrowest operative end along a filtering axis in optical communication between the input and receiver waveguides. An actuator moves the wedged-etalon and optically aligned input and receiver waveguides

relative to one another along the filtering axis to select positions between the widest and narrowest operative ends to drop a select channel. The selectively reflective means may be a reflective optic between the receiver optical waveguide and the second receiver optical waveguide. An actuator is provided for moving the reflective optic into an out of optical communication with the receiver optical waveguide. The second receiver optical waveguide and the receiver optical waveguide are in optical communication when the reflective optic is out of optical communication with the receiver optical waveguide.

Yet another aspect of the present invention is a method for dropping a select channel of multi-channel optical signal propagated along a main optical waveguide without loss of data. The method includes directing a multi-channel optical signal from the main optical waveguide to an input waveguide. A receiver waveguide is optically aligned with the input waveguide. A tunable transmission filter is provided in optical communication between the input and receiver waveguides. The tunable transmission filter is tuned to drop a select channel to the receiver optical waveguide and to reflect the remaining channels of the multi-channel optical signal to a retransmission optical waveguide in optical communication with the main optical filter. All dropped channels are reflected for repropagation along the main optical waveguide while the tunable transmission filter is tuned between first and second select channels. After tuning the select dropped channel is no longer repropagated along the main optical axis. The tunable transmission filter may be a wedged-etalon having a cavity that varies uniformly in width between a widest operative end and a narrowest operative end along filtering axis. The wedged-etalon has select positions along the tuning axis, each dropping a select channel and reflecting all other channels. The wedged-etalon is tuned by directing the multi-channel optical signal from the input waveguide to a select position along the filtering axis to drop a corresponding channel to the receiver optical waveguide. The step of reflecting all dropped channels for repropagation may include providing a reflective optic and moving the reflective optic into optical communication with the dropped channel.

The reconfigurable add/drop multiplexer and methods for dropping a select channel of a multi-channel optical signal of the present invention achieve the high resolution available from Fabry-Perot devices without the need to actively control a gap in spacing between reflective panels by using a wedged-etalon filter with a static but varying gap spacing. Thus,

the requirement of using highly precise piezoelectric actuators and a highly engineered mounting mechanism to control gap spacing is eliminated. Instead, different wavelengths may be selectively transmitted by changing the position at which an input multi-channel optical signal strikes the wedged-etalon. This can be done by moving the input and receiver
5 fibers in concert relative to the etalon or moving the etalon relative to the input and receiver fibers. The use of a wedged-etalon allows for much simpler, robust devices which may be manufactured more economically than prior art devices while maintaining the high resolution characteristic of Fabry-Perot devices. The wedged-etalon is a medium finesse filter. It provides high resolution (0.08nm over a large wavelength range) that allows for more closely
10 spaced wavelengths to be multiplexed or de-multiplexed onto or off of a single fiber, thereby increasing the capacity of the fiber. Thus, the apparatus and method of the present invention provides a reconfigurable add/drop multiplexer for a single channel with a much larger bandwidth that can enable denser multiplexing onto dense wavelength division multiplexing network systems than is possible with current technology. By way of contrast, current dense
15 wavelength division multiplexing (DWDM) apparatus have a channel spacing that is limited to approximately 0.8 nm over a relatively narrow spectral range. The present invention facilitates increasing the number of channels being transmitted over a fiber backbone of an optical network from approximately 30-40 to over 300. The present invention further provides a method and apparatus to prevent the loss of data during tuning of the wedged-
20 etalon or other tunable filters to assure the integrity of the multi-channel optical signal. The method and apparatus are easily and inexpensively implemented.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic representation of a normal air-spaced etalon;

25 Fig. 2 is the resulting transmission spectrum of the normal etalon of Fig. 1;

Fig. 3 is a schematic representation of a wedged-etalon in accordance with the present invention;

Fig. 4 is the resulting transmission spectrum as a function of position on the wedge of Fig. 3;

Figs. 5A-5C are schematic representations of a first embodiment of a reconfigurable drop multiplexer of the present invention using the wedged-etalon of Fig. 3 as a transmission filter;

Fig. 6 is an embodiment of a reconfigurable add/drop multiplexer in accordance with the present invention including both transmission and reception functions;

Figs. 7A-7C are schematic representations of an embodiment of a drop multiplexer in accordance with the present invention including a mirror for preventing the dropping of intermediate channels during tuning of the wedged-etalon;

Fig. 8 is a schematic representation of a second embodiment of a reconfigurable add/drop multiplexer including a mirror for preventing the dropping of intermediate channels during tuning;

Fig. 9 is a third embodiment of a reconfigurable add/drop multiplexer using a pair of wedged-etalon filters in series to prevent the dropping of intermediate channels during tuning; and

Fig. 10 is a fourth embodiment of a reconfigurable add/drop multiplexer using a 2 x 2 optical switch to prevent the dropping of intermediate channels during tuning.

DETAILED DESCRIPTION OF THE INVENTION

A normal air-spaced etalon 10 is shown schematically in Fig. 1. It consists of a pair of transparent substrates 12, 14, each having opposing reflective surfaces 16, 18. For use with light having a bandwidth between 1534 – 1561 nanometer (nm), the free spectral range (FSR) is 27 nm. For an etalon,

$$\text{FSR} = 1/(2d) \text{ (Equation 1)}$$

with the FSR expressed in wave numbers ("W_n") and d equal to the average thickness of the etalon over the FSR. W_n = 1/wavelength (nm), so here FSR = (1/1561 (nm)) – (1/1534 (nm)) = 112.0 cm⁻¹. Solving for d in Equation 1, d = 1/(2x112 cm⁻¹) = 44.64 microns (μ). This would be the average calculated etalon thickness, A.

The desired channel width (Δv) is equal to the FSR divided by F, where F is equal to the finesse of the etalon, or

$$\Delta v = \text{FSR}/F \text{ (Equation 2)}$$

Here the desired channel width is approximately 0.09 nm and the FSR equals 27 nm. Thus, $F = 27 \text{ nm} / 0.09 \text{ nm} = 300$.

The finesse and reflectivity (R) of the etalon surfaces are related as follows:

$$F = \pi R^{1/2} / (1 - R) \quad (\text{Equation 3})$$

- 5 Solving for R, R is equal to 0.99. Thus, the dimensions and properties of the etalon Fig. 1 can be summarized as follows:

Reflectivity, $R = 99\%$

Finesse = 300

$d = 44.64 \mu$

10 FSR = 27 nm

Fig. 2 represents the resulting transmission spectrum of the etalon of Fig. 1.

- Fig. 3 is a schematic representation of an exemplary wedged-etalon for use in accordance with the present invention. The etalon is similar to the etalon 12, only the substrates are inclined to form a "wedge". As with the etalon of Fig. 1, this exemplary
 15 wedged-etalon is intended to operate from 1534–1561 nm, thus requiring a respectral range ("FSR") of 27 nm, although much wider wavelength ranges of 1520-1610 nm or more are also possible. Within this 1534-1561 nm wavelength range, there are intended to be 32 channels available, with an extra channel position to reflect all wavelengths. This allows for a desired channel spacing of 0.8 nm. However, channel spacing of 0.4 nm or less is also possible,
 20 which would yield a greater channel density.

Applying equation 1 above, the average calculated etalon thickness would be equal to 44.64μ , the same as the etalon illustrated in Fig. 1.

- With an average calculated etalon thickness of 44.64μ , the precise thickness must be calculated so that a whole number of wavelengths fit into the etalon cavity. Number of
 25 wavelengths is equal to the average etalon thickness (μ)/average wavelength (μ), or $46.64 \mu / 1.5475(\mu) = 28.84$, or approximately 29. The precise thickness then must be 29 multiplied by the wavelength, or with the wavelength varying between 1534-1561 nm, the thickness varies between $29 \times 1534 \text{ nm} = 44.486 \mu$ and $29 \times 1561 \text{ nm} = 45.269 \mu$, for a total variation of 0.783μ .

For manufacturability, an etalon length of 1 cm is preferred. However, it is necessary to verify whether an etalon of 1 cm length will afford adequate spacing to resolve the channels. A practical limit for the diameter of a collimated light beam is 30μ (30×10^{-4} cm). The etalon is required to tune 27 nm of bandwidth over its 1 cm length, yielding a channel width of 30×10^{-4} cm \times 27 nm/cm = 0.081 nm. The resolution or channel width is $\Delta v = \text{FSR}/F$ (Eq. 2), where F is the finesse of the etalon. $F = \pi R^{1/2}/(1-R)$ (Eq. 3), where R is the reflectivity of the etalon surfaces. To provide a channel width of 0.09 nm (> 0.081), $F = 27/0.09 = 300$. This requires $R \approx 0.99$, which is readily achievable.

In summary, the dimensions of the wedged-etalon for this example are as follows:

Length (L) = 1.0 cm

Reflectivity (R) = 99%

Finesse = 300

Variation in etalon thickness (d) over 1 cm length of filtering axis between narrowest and widest operative ends: $d = 44.486\mu$ to $d = 45.269\mu$

FSR = 27 nm

Fig. 4 illustrates the resulting transmission spectrum as a function of light impinging on the wedged-etalon at positions 1, 2, 3 of Fig. 3. In this example, the wedged-etalon has 32 positions along the filtering axis which each drop a corresponding select wavelength channel, and a 33rd position that reflects all channels. Obviously, if a greater channel density and/or greater FSR were chosen, the number of channels could be much larger.

A first embodiment of the present invention is a single wavelength drop demultiplexer shown schematically in Fig. 5A. A multi-channel optical signal 24 (or dense wavelength multiplexed beam of light) is emitted from input waveguide or optical fiber 26 and collimated by the collimating lens 28. In the embodiments described herein, optical fibers are used as waveguides. It should be appreciated by those skilled in the art that other waveguides may be suitable as well, such as planar waveguides formed on monolithic substrates. Telecommunications optical fibers have a core diameter of between 6-9 microns. The multi-channel optical signal 24, in this example consisting of wavelengths λ_{1-32} , impinges at position 1 along the filtering axis of the wedged-etalon 20 at an angle of $90^\circ - \theta$. In position 1, which is the widest operative end of the wedge, the reddest wavelength (1561 nm

for this embodiment, λ_{32}) is transmitted through the etalon to the receiver fiber 30, which is optically aligned with the input fiber 26. The channel λ_{32} is focused by the focusing optic 34 before entering the receiver fiber 30. The remaining channels of the multi-channel optical signal, $\lambda_{1,31}$, are reflected off the surface of the wedged-etalon 20 to retransmission fiber 34 through focusing optic 35.

The focusing and collimating optics may be, by way of example, a graded index lens, an aspheric lens or the like. The focusing and collimating optics may be separate elements as shown, or may be integrated on to the fiber ends as a monolithic device.

As used herein, the input fiber 26 and the receiver fiber 30 are "optically aligned", which means channels emitted from the input fiber are directed to the receiver fiber for reception thereby. The input fiber and the output fiber are "optically coupled" or in "optical communication" with the wedged-etalon 20. As used herein, "optically coupled" or in "optical communication" means any connection, coupling, link, or the like, by which optical signals carried by one optical element are imparted to the "coupled" or "communicating" element. Such "optically communicating" devices are not necessarily directly connected to one another, but may be separated by a space through which the optical signals traverse or by intermediate optical components or devices. In addition, signals need not continuously traverse between the components or devices but may be selectively interrupted by intermediate components or devices.

An electro-mechanical device, or actuator 36, is operatively connected to the wedged-etalon 20 to move the wedged-etalon to other positions relative to the input fiber 26 and receiver fiber 30 along its filtering axis to drop other select channels. Alternatively, the actuator 36 could be coupled to the input and receiver fibers to move them relative to the wedged-etalon. Representative electro-mechanical devices could include solenoid actuators, stepper motors, piezo electric devices, bimetallic actuators and the like. One potentially suitable electro-mechanical device is described in Scobey, *et al.*, PCT Pub. No. WO 00/39626, the disclosure of which is incorporated by reference herein. The essential features of the electro-mechanical device 36 is that it be able to control the position of the wedged-etalon 20 with up to one micron precision. The actuator 36 has a digital interface to a network control system (not shown) which sends a digital signal to the actuator indicating the

wavelength of a channel to be dropped and the wedged-etalon is moved accordingly by the actuator.

In Fig. 2, the wedged-etalon is moved to position 2 relative to the input fiber 26 and receiver fiber 30. Here the light impinges on the thinnest operative end of the wedge. This end of the wedge transmits the bluest light ($\lambda_1 = 1534$ nm for this embodiment). Further down the etalon, at position 3 illustrated in Fig. 5C, even bluer light would be transmitted, but there is no light at wavelengths shorter than 1528 nm on the network backbone. Therefore, at position 3, the wedged-etalon transmits none of the wavelengths λ_{1-32} and all of wavelengths λ_{1-32} are reflected to the retransmission fiber 34.

A second embodiment of the present invention shown in Figure 6 is a add/drop multiplexer 37. The add/drop multiplexer is very similar to the single wavelength drop demultiplexer 22 and like elements have the same reference number. The add/drop multiplexer 37 differs by the inclusion of a transmission fiber 38 and the focusing optic 39 which are optically aligned with the retransmission fiber 34. As illustrated in Fig. 6, the retransmission fiber 34, transmission fiber 38, receiver fiber 30, and input fiber 26 form an "X" across the wedged-etalon at an angle of about $90^\circ - \theta$ from the surface of the wedged-etalon.

Figure 6 includes two identical add/drop multiplexers 37 operating as access terminals on a main optical fiber 40 which forms an optical network. Here, by way of example, a first computer 41 is optically coupled to node 1 and includes a receiver 42 optically coupled to receiver fiber 30 and a transmitter 43 optically coupled to transmission fiber 38. A second computer 44 is optically coupled to node 2 and includes receiver 45 and transmitter 46. For the first computer 41 and the second computer 44 to communicate, they must do so using a channel of the same wavelength, here λ_{32} . As described above with regard to the drop demultiplexer 22, the wedged-etalon 20 at node 1 is in a select position along its filtering axis to drop the select channel λ_{32} to the receiver fiber 30, which in turn is optically coupled to the receiver 42. The first computer 41 communicates with the second computer 44 by transmitting an optical signal λ'_{32} at the same wavelength as the dropped channel λ_{32} and this channel is propagated to the retransmission fiber 34 through the indicated position of the wedged-etalon 20 for repropagation along the main fiber 40. At node 2, the wedged-etalon 20 is at the identical position as the wedged-etalon 20 of the add/drop multiplexer at node 1 so

that the channel λ'_{32} is dropped to the receiver 45 of the second computer 44 via the receiver fiber 30. The second computer 44 transmits via transmitter 46 signal λ_{32} which is repropagated to the main fiber 40 in the same manner discussed above with regard to node 1. Assuming that the input fibers 26, receiver fiber 30, retransmission fiber 34, and transmission fiber 38 all form the same angle, θ , with respect to the wedged-etalon, the wavelength that is removed from the backbone by the wedged-etalon will be identical to the laser transmitted wavelength that is passed through the wedged-etalon and on to the backbone 40 by the transmitter 43, 46. If communication between more than two nodes is to occur at the same time, the first receiver node must repeat the data for the next receiver node to receive.

The reconfigurable add/drop multiplexer 37 is useful in wide area networks (WAN), metro networks, and long haul networks. One potential problem with the above configuration is that as the wedged-etalon is moved along its filtering axis so as to change the transmitted channel between a first and a second wavelength, intermediate channels of wavelengths between the first and second channels will be transmitted through the wedged-etalon, resulting in a loss of data intended for further transmission. One way to eliminate this loss is illustrated schematically with respect to a second embodiment of a drop multiplexer 48 in Figs. 7A-7C. This embodiment is identical to the first embodiment of the drop demultiplexer 22 with the inclusion of a selectively reflective device, here a reflective optic, preferably a mirror 50, controlled by actuator 51. Referring to Fig. 7A, mirror 50 is moveable up and down as indicated by arrow 52 by a suitable electro-mechanical actuator 51 having a digital interface to a network control system, as does the actuator 36. With the wedged-etalon in position 1 illustrated in Fig. 7A, a channel of light of a wavelength λ_{32} is transmitted to the receiver fiber 30 and wavelengths λ_{1-31} are reflected to return fiber 34. When it is desirable to reconfigure the wedged-etalon to transmit a second wavelength e.g., λ_1 , mirror 50 is first raised to intercept and reflect the entirety of the multi-channel input beam λ_{32} to the return fiber 34. Thereafter the etalon 20 is moved to a position 2 along its filtering axis to transmit λ_1 by actuator 37 (See Fig. 7B). The mirror 50 is then moved downward so that wavelength λ_1 is transmitted to the receiver fiber 30 and the wavelengths λ_{2-32} are reflected to the receiver fiber 34. See Fig. 7C. In this manner, none of wavelengths λ_{1-32} are dropped from the main optical line during reconfiguration of the drop multiplexer.

Fig. 8 schematically illustrates a second embodiment of a reconfigurable add/drop multiplexer 60 in accordance with the present invention. The add/drop multiplexer 60 includes a three port optical circulator 62 having first, second and third ports 64, 66, 68. A main optical fiber 63 is connected to the first port 64 and the third port 68. A branch fiber, or input fiber 70, is connected to the second port 66. The optical circulator directs substantially all of the light transmitted into the first port 64 into the input optical fiber 70, regardless of wavelength. The input optical fiber outputs to a collimating lens 72 which directs the entire light signal or light beam on to the wedged-etalon 74. In accordance with the discussion above, the wedged-etalon can be moved in the direction of the angle of the arrow 76 by actuator 77 to a select position along its filtering axis to transmit a channel of a desired wavelength through the wedged-etalon to the collimating lens 78, into the receiver fiber 80 and on to receiver 82 as directed by a network control system. In order to prevent dropping of intermediate wavelengths while the wedged-etalon 74 is being moved to pass a second select wavelength, a mirror 84 can be moved in and out of the beam in the direction of the arrow 86 by actuator 87 as directed by a network control system. Thus, before the wedged-etalon 74 is moved, the mirror 84 is brought into position to reflect the entirety of the beam back into the input fiber 70 into the second port and then out the third port where the entire beam is repropagated to the main optical fiber 63. Once the wedged-etalon 74 is in the necessary position to drop the second select wavelength, the mirror 84 is moved out of the beam and the desired wavelength passes through the wedged-etalon to the receiver 82 with the remaining wavelengths being reflected back up the input optical fiber and onto the main optical fiber 63 in the manner discussed above.

Optical data signals can be added to the main optical fiber 63 by an optical transmitter 86, which is optically coupled to the main optical fiber 63 through a second branch optical fiber 88 by a 1x2 directional coupler 90. The wavelength of the optical data signals produced by the transmitter 86 are substantially the same as the optical data signals dropped to the receiver 82.

The embodiments illustrated in Figs. 5-8 still present a potential loss of data during movement of the mirror. This can be avoided by the third embodiment of an add/drop multiplexer illustrated schematically in Fig. 9.

The third embodiment of an add/drop multiplexer 100 uses two optical circulators 102, 104 and two wedged-etalon tunable filters 106, 108 positioned by the actuators 107, 109. The circulator 102 has a first port 110, a second port 112 and a third port 114. The main optical fiber 116 is coupled to the first port 110 and the third port 114. The second port 112 is coupled to branch or input fiber 118. Input fiber 118 in turn is optically coupled with the first tunable filter 106 in the manner discussed above, and a collimating focusing optic (not shown) may be provided to collimate the beam from the input fiber 118. Receiver fiber 120 is optically coupled and aligned with input fiber 118 and receives the channel transmitted through the tunable filter with the remaining channels being reflected up the input optical fiber 118 through the circulator for repropagation along the main optical fiber 116 through the third port 114. The second circulator 104 has a first port 122, a second port 124 and a third port 126. The receiver fiber 120 is coupled to the first port 122 and a second retransmission fiber 128 is coupled to the third port 126. A second input or branch fiber 130 is coupled to the second port 124 and it in turn directs the transmitted channel to the second wedged-etalon 108. Second receiver fiber 132 receives the wavelength transmitted through the second wedged-etalon 108 and the wedged-etalon reflects the remaining wavelengths up the second input optical fiber 130 to the circulator 104 with the reflected wavelengths being transmitted out of the third optical port 126 into the retransmission fiber 128. The reflected wavelengths are repropagated to the main optical fiber 116 through a 1x2 directional coupler 134 for propagation along the main optical fiber 116.

The embodiment 100, like the embodiment 60, functions to prevent the loss of intermediate channels during tuning of the wedged-etalon 106. In use, when a new wavelength is to be dropped, the second wedged-etalon 108 (or alternatively, another reflective optic such as a mirror), is first moved by actuator 109 from the position necessary for transmitting the desired wavelength. During this period, no wavelength is transmitted to the second receiver fiber 132. Indeed, all wavelengths are re-propagated to the main optical fiber during this period as the single wavelength passing through the first wedged-etalon 106 is reflected by the second wedged-etalon 108 (or mirror) and back through the second branch fiber 130 and the retransmission fiber 128 to the 1x2 directional coupler 134. Once the second wedged-etalon is in the necessary position to drop the desired channel, the first tunable

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filter 106 is moved to a position to drop the select channel by actuator 107. Thereafter the select channel passes to the receiver fiber 120 and passes through the second wedged-etalon 108 to the second receiver fiber 132. In this manner, the embodiment 100 prevents the dropping of intermediate channels during tuning. Thus, only the channel desired to be
5 dropped is dropped and the integrity of the optical signal is maintained. Movement of the wedged-etalon 106, 108 can be controlled by a controller 136 coupled to the actuators 107, 109.

The embodiments illustrated in Figs. 7-9 are shown using a mirror as a reflective optic that is moved by an actuator. Alternatively, the reflective optic could be a selectively
10 transmissive electro-optic device such as that disclosed in Birnach, U.S. Patent No. 4,786,128, the disclosure of which is incorporated by referenced herein. Use of such a selectively reflective device would eliminate moving parts, always a desired goal.

A fourth embodiment of an add/drop multiplexer 150 is shown schematically in Fig. 10. This embodiment uses an optical circulator 152 having first, second and third optical
15 ports 154, 156, 158. A main optical fiber 160 is optically coupled to the first and third ports 154, 158. The second port 156 is optically coupled to a branch or input fiber 162. The input fiber 162 in turn is optically coupled to a tunable filter 164 in the manner discussed above. The tunable filter is preferably a wedged-etalon. A collimating optic (not shown) may be provided to collimate the multi-channel beam from the input fiber 162. Receiver fiber 166 is
20 optically coupled and aligned with input fiber 162 and receives channels transmitted through the tunable filter 164, with the remaining channels being reflected up the input fiber 162 and through the circulator for repropagation along main optical fiber 160 through the third port 158. A focusing optic (not shown) may focus the signal to the receiver fiber. A 2 x 2 optical switch 168 has first, second, third and fourth ports 170, 172, 174, 176. Receiver fiber 166 is
25 coupled to the first port 170 and an optical receiver 178 is coupled to the third port 174. An optical transmitter 180 is coupled to the second port 172 and a transmission fiber 182 is coupled to the fourth port 176. Transmission fiber 182 is also coupled to a 1 x 2 directional coupler 184. The 1 x 2 directional coupler is coupled to the main optical fiber 160 as shown in Fig. 10. When a select first channel is being dropped by the wedged-etalon 164, the 2 x 2
30 switch 168 is configured to direct the dropped channel from the first port 170 to the third port

174 and on to the receiver 178. Simultaneously, a channel from the transmitter at the same wavelength as the dropped channel may be propagated to the second port 172 and on to the fourth port 176 for propagation along the main optical fiber 160. This is a "talk mode", illustrated in solid lines. When the wedged-etalon 164 is to be tuned between a first and a second dropped channel, the optical switch 168 is first reconfigured to direct the dropped channel to the fourth port 176 for repropagation along the main optical fiber 160. This is a "tune mode" and is illustrated in dashed lines. As the etalon is tuned by movement along its tuning axis by an actuator (not shown) between the first and a second select channel, all dropped channels are likewise repropagated along the main optical fiber 160. Once the second channel is tuned, the switch 168 is again reconfigured to the talk mode. In this manner, data integrity is maintained during tuning of a wedged-etalon 164.

Each of the embodiments illustrated in Figs. 5-10 could be used with the wedged-etalon described with respect to Fig. 3. Alternatively, for a different wavelength range or greater channel density, wedged-etalon of different dimensions derived in accordance with the teachings herein could be used.

The reconfigurable add/drop multiplexers of the present invention allows a large number of wavelengths to be multiplexed on a backbone fiber as opposed to current add/drop multiplexers using fiber-Bragg grating. Fiber Fabry-Perot (FFP) devices offer similar benefits in terms of bandwidth; however, FFP's are complex devices in terms of their electro-mechanical design. They require their gap spacing to be actively controlled to a sub-nanometer resolution. The wedged-etalon of the present invention requires no movement of the mirrored surfaces relative to each other. This design provides a much more robust reconfigurable add/drop multiplexer which can be manufactured at lower cost. The present invention also enables switching between channels without loss of data from intermediate channels during the switching to maintain signal integrity.

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CLAIMS

What is claimed is:

- 5 1. A reconfigurable add/drop multiplexer for use in an optical communications network comprising:
- an input optical waveguide propagating a multichannel optical signal;
a receiver optical waveguide optically aligned with the input waveguide;
a wedged-etalon having a cavity that varies uniformly in width between a widest
10 operative end and narrowest operative end along a filtering axis in optical communication between the input and receiver waveguides; and
- means for moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another along the filtering axis to select positions between the widest and narrowest operative ends to selectively drop a select channel of the multichannel
15 optical signal corresponding to the select position of the receiver waveguide.
2. The reconfigurable add/drop multiplexer of claim 1 further comprising a collimating optic between the input waveguide and the wedged-etalon.
3. The reconfigurable add/drop multiplexer of claim 2 further comprising a focusing optic between the receiver waveguide and the wedged-etalon.
- 20 4. The reconfigurable add/drop multiplexer of claim 1 further comprising a retransmission waveguide in optical communication with the wedged-etalon, the wedged-etalon reflecting all channels but a select dropped channel to the retransmission waveguide.
5. The reconfigurable add/drop multiplexer of claim 4 wherein the input waveguide and the retransmission waveguide are the same waveguide.
- 25 6. The reconfigurable add/drop multiplexer of claim 1 wherein the moving means is an electro-mechanical actuator operatively associated with the wedged-etalon.
7. The reconfigurable add/drop multiplexer of claim 1 wherein each of the input and receiver waveguides are optical fibers.
8. The reconfigurable add/drop multiplexer of claim 4 further comprising a
30 transmission waveguide in optical communication with the retransmission waveguide, the transmission waveguide being located on a side of the wedged-etalon opposite the

retransmission waveguide and directing a transmission channel of a select position corresponding to a dropped channel.

5 9. The reconfigurable add/drop multiplexer of claim 8 wherein the input waveguide, the receiver waveguide and the retransmission waveguide each have an optical axis forming an equivalent angle relative to the surface of the wedged-etalon at each select position.

10 10. The reconfigurable add/drop multiplexer of claim 8 further comprising an optical transmitter optically coupled to the transmission waveguide, the transmitter propagating a channel having a wavelength equivalent to that of the select dropped channel.

11. The reconfigurable add/drop multiplexer of claim 4 further comprising:
a reflective optic; and
means for moving the reflective optic relative to the input and retransmission optical waveguides to reflect the multichannel optical signal to the retransmission waveguide before the multichannel optical signal strikes the wedged-etalon.

15 12. The reconfigurable add/drop multiplexer of claim 4 further comprising:
a second receiver waveguide optically coupled with the receiver waveguide;
a reflective optic between the receiver optical waveguide and the second receiver optical waveguide;

20 means for moving the reflective optic into and out of optical communication with the receiver optical waveguide, the second receiver optical waveguide and the receiver optical waveguide communicating optical signals when the reflective optic is out of optical communication with the receiver optical waveguide; and

25 a second retransmission waveguide in optical communication with the reflective optic to receive a reflected optical signal when the reflective optical waveguide is in optical communication with the receiver optical waveguide.

13. The reconfigurable add/drop multiplexer of claim 12 wherein the reflective optic is a second wedged-etalon identical to the first wedged-etalon, whereby with the first wedged-etalon at a select position and the second wedged-etalon at the same select position a select channel is propagated to the second receiver optical waveguide.

14. The reconfigurable add/drop multiplexer of claim 1 further comprising the wedged-etalon having a non-drop position along the filtering axis reflecting all channels of the multi-channel optical signal.

15. The reconfigurable add/drop multiplexer of claim 1 wherein the cavity of the
5 wedged-etalon varies between 44.486μ and 45.269μ between the narrowest and widest operative ends.

16. The reconfigurable add/drop multiplexer of claim 15 wherein the wedged-etalon is about 1 cm in length between the narrowest and widest operative ends.

17. The reconfigurable add/drop multiplexer of claim 16 wherein the reflectivity of
10 the etalon surfaces is about 0.99.

18. A method of dropping a select channel of a multichannel optical signal propagated along a main optical waveguide comprising:

directing the multichannel optical signal from the main optical waveguide to an input waveguide;

15 optically aligning a receiver waveguide with the input waveguide;

providing a wedged-etalon having a cavity that varies uniformly in width between a widest operative end and narrowest operative end along a filtering axis in optical communication between the input and receiver waveguides; and

20 moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another along the filtering axis to a first select position between the widest and narrowest operative ends to drop a select channel of the multichannel optical signal corresponding to the select position to the receiver waveguide.

19. The method of claim 18 further comprising reflecting all of the multichannel optical signal except the select dropped channel to a retransmission waveguide in optical
25 communication with the main optical waveguide.

20. The method of claim 19 wherein the input waveguide and the retransmission waveguide are the same waveguide.

21. The method of claim 18 wherein each waveguide is an optical fiber.

22. The method of claim 19 further comprising transmitting a channel of a wavelength equivalent to the dropped channel through the select position of the wedged-etalon into the retransmission waveguide.

23. The method of claim 19 further comprising reflecting all of the multichannel optical signal to the retransmission waveguide while the moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another along the filtering axis between select positions.

24. The method of claim 19 further comprising reflecting all dropped channels for repropagation along the main optical waveguide while the moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another along the filtering axis between select positions.

25. The method of claim 18 further comprising providing a second wedged-etalon identical to the first wedged-etalon, the second wedged-etalon being in optical communication with the receiver waveguide;

15 moving the second wedged-etalon along the filtering axis from a first to a second select position before moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another from a first to a second select position;

moving the wedged-etalon and the receiver waveguide relative to one another along the filtering axis from the first to the second select positions after moving the second wedged-etalon to the second select position to drop the second select channel; and

20 reflecting all intermediate channels between the first and second channel dropped by the wedged-etalon off the second wedged-etalon for repropagation along the main optical fiber while moving the wedged-etalon from the first to the second select positions.

26. A method of dropping a select channel of a multichannel optical signal propagated along a main optical waveguide comprising:

directing the multichannel optical signal from the main optical waveguide to an input waveguide;

optically aligning a receiver waveguide with the input waveguide;

30 providing a wedged-etalon having a cavity that varies uniformly in width between a widest operative end and narrowest operative end along a filtering axis in optical

communication between the input and receiver waveguides, the wedged-etalon being configured to have select positions along the filtering axis dropping a corresponding select channel of the multichannel optical signal;

directing the multichannel optical signal from the input waveguide to a select position
5 along the filtering axis to drop a corresponding select channel; and
reflecting all of the multichannel optical signal except the dropped channel to a retransmission waveguide in optical communication with the main optical waveguide.

27. The method of claim 26 wherein each optical waveguide is an optical fiber.

28. The method of claim 26 wherein the input waveguide and the retransmission
10 waveguide are the same waveguide.

29. The method of claim 26 further comprising transmitting a channel of a wavelength equivalent to the dropped channel through the select position of the wedged-etalon into the retransmission waveguide.

30. The method of claim 26 further comprising changing the dropped channel
15 between first and second dropped channels by directing the multichannel optical signal from a first to a second corresponding position along the filtering axis.

31. The method of claim 30 further comprising reflecting all of the multichannel optical signal to the retransmission waveguide for repropagation along the main optical waveguide while changing the dropped channel between first and second dropped channels.

20 32. The method of claim 30 further comprising reflecting all dropped channels for repropagation along the main optical waveguide while changing the dropped channel between first and second dropped channels.

33. A reconfigurable add/drop multiplexer for use in an optical communications network comprising:

25 an input optical waveguide propagating a multichannel optical signal;
a receiver optical waveguide optically aligned with the input waveguide;
a transmission filter in optical communication between the input optical waveguide and the receiver optical waveguide, the transmission filter being tunable to drop a select channel to the receiver optical waveguide and to reflect the remaining channels of the
30 multichannel optical signal;

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a retransmission waveguide in optical communication with the transmission filter to receive the reflected remaining channels;

a second receiver waveguide in optical communication with the receiver waveguide;

5 a selectively reflective means in optical communication between the receiver optical waveguide and second receiver optical waveguide for selectively reflecting the dropped channel or transmitting the dropped channel to the second receiver optical waveguide; and

a second retransmission waveguide in optical communication with the selectively reflective means to receive a reflected optical signal.

10 34. The reconfigurable add/drop multiplexer of claim 33 further comprising:
a main optical waveguide propagating the multichannel optical signal;
a first optical circulator in optical communication with the main optical waveguide and the input optical waveguide directing the multichannel optical signal to the input optical waveguide;

15 the input optical waveguide and the retransmission optical waveguide being a single waveguide; and

the optical circulator receiving the reflected remaining channels and repropagating them along the main optical waveguide.

20 35. The reconfigurable add/drop multiplexer of claim 34 further comprising:
a second optical circulator in optical communication with the receiver waveguide and a second input waveguide directing the dropped select channel to the second input waveguide, the second input waveguide being optically aligned with the second receiver waveguide;

the second input waveguide and the second retransmission waveguide being a single waveguide; and

25 the optical circulator receiving the reflected dropped channel and directing the reflected dropped channel for repropagation along the main optical waveguide.

36. The reconfigurable add/drop multiplexer of claim 33 wherein each optical waveguide is an optical fiber.

37. The reconfigurable add/drop multiplexer of claim 33 wherein the transmission filter comprises:

24

a wedged-etalon having a cavity that varies uniformly in width between a widest operative end and narrowest operative end along a filtering axis in optical communication between the input and receiver waveguides; and

means for moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another along the filtering axis to select positions between the widest and narrowest operative ends to drop a select channel.

38. The reconfigurable add/drop multiplexer of claim 33 wherein the selectively reflective means comprises:

a reflective optic between the receiver optical waveguide and the second receiver optical waveguide; and

means for moving the reflective optic into and out of optical communication with the receiver optical waveguide, the second receiver optical waveguide and the receiver optical waveguide being in optical communication when the reflective optic is out of optical communication with the receiver optical waveguide.

39. A method of dropping a select channel of a multichannel optical signal propagated along a main optical waveguide without loss of data comprising:

directing the multichannel optical signal from the main optical waveguide to an input waveguide;

optically aligning a receiver waveguide with the input waveguide;

providing a tunable transmission filter in optical communication between the input and receiver waveguides;

tuning the tunable transmission filter to drop a select channel to the receiver optical waveguide and to reflect the remaining channels of the multichannel optical signal to a retransmission optical waveguide in optical communication with the main optical fiber; and

repropagating all dropped channels along the main optical waveguide while tuning the tunable transmission filter between first and second select channels.

40. The method of claim 39 wherein each optical waveguide is an optical fiber.

41. The method of claim 39 wherein the tunable transmission filter is a wedged-etalon having a cavity that varies uniformly in width between a widest operative end and narrowest operative end along a filtering axis, the wedged-etalon being configured to have

select positions along the tuning axis each dropping a select channel and reflecting all other channels and the tuning step comprises directing the multichannel optical signal from the input waveguide to a select position along the filtering axis to drop the select channel to the receiver optical waveguide.

5 42. The method of claim 39 wherein the repropagating step comprises providing a reflective optic and moving the reflective optic into optical communication with the dropped channel.

 43. The method of claim 42 wherein the reflective optic is a mirror.

 44. The method of claim 39 wherein the repropagating step comprises providing
10 an optical switch in optical communication with the dropped channels, the optical switch in a first state directing the dropped channels for repropagation along the main optical waveguide and in a second state not directing the dropped channel for repropagation.

 45. A reconfigurable add/drop multiplexer for use in an optical communications network for selectively dropping channels of a multi-channel optical signal propagated along
15 a main optical waveguide without data loss comprising:

 an input optical waveguide optically coupled to the main optical waveguide
propagating a multi-channel optical signal;

 a receiver optical waveguide optically aligned with the input waveguide;

 a transmission filter in optical communication between the input optical waveguide
20 and the receiver optical waveguide, the transmission filter being tunable to drop a select channel to the receiver optical waveguide and to reflect the remaining channels of the multi-channel optical signal;

 a retransmission waveguide in optical communication with the transmission filter and
main optical waveguide to receive the reflected remaining channels and repropagate them
25 along the main optical waveguide; and

 means for repropagating all dropped channels to the main optical waveguide as the transmission filter is tuned between first and second dropped channels optically coupled to the receiver optical waveguide.

 46. The reconfigurable add/drop multiplexer of claim 45 wherein the
30 repropagating means comprises a 2 x 2 optical switch optically coupled to the receiver

waveguide, a receiver, a transmitter and a transmission waveguide, the transmission waveguide further being optically coupled to the main optical fiber, the optical switch having a talk state optically coupling the receiver waveguide to the receiver and the transmission waveguide to transmitter and a tune state optically coupling the receiver waveguide to the transmission waveguide.

47. The reconfigurable add/drop multiplexer of claim 45 wherein each optical waveguide is an optical fiber.

48. The reconfigurable add/drop multiplexer of claim 45 wherein the transmission filter comprises:

a wedged-etalon having a cavity that varies uniformly in width between a widest operative end and narrowest operative end along a filtering axis in optical communication between the input and receiver waveguides; and

means for moving the wedged-etalon and optically aligned input and receiver waveguides relative to one another along the filtering axis to select positions between the widest and narrowest operative ends to drop a select channel.

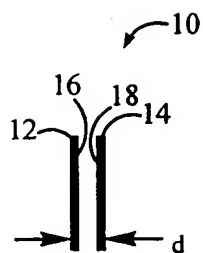


Fig. 1

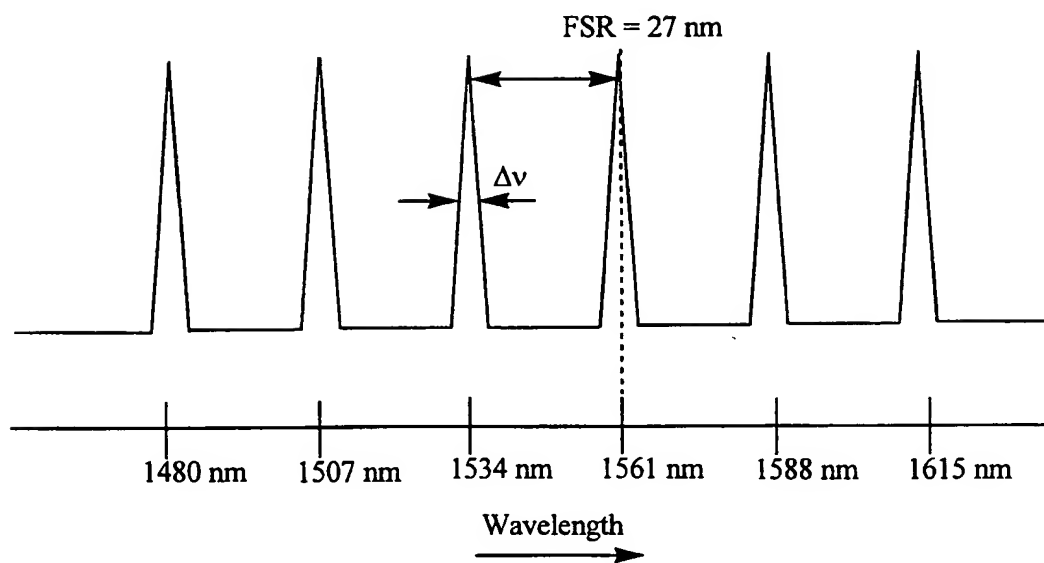


Fig. 2

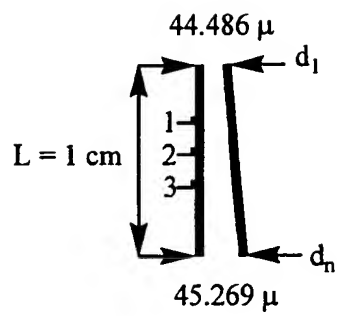


Fig. 3

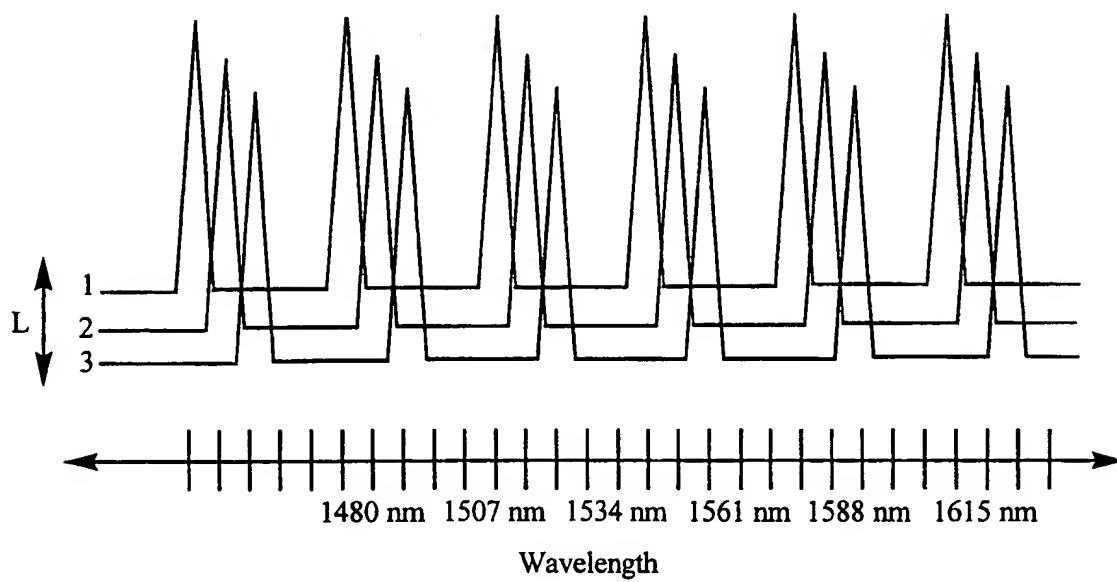


Fig. 4

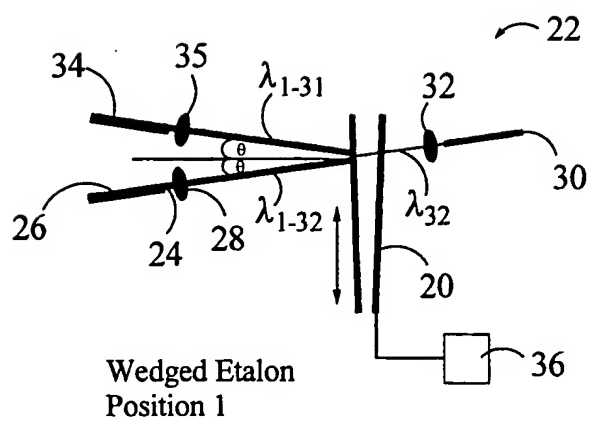


Fig. 5A

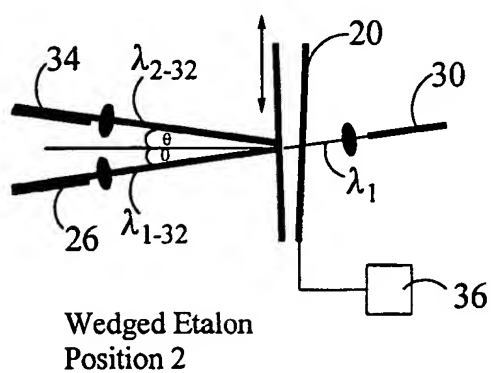


Fig. 5B

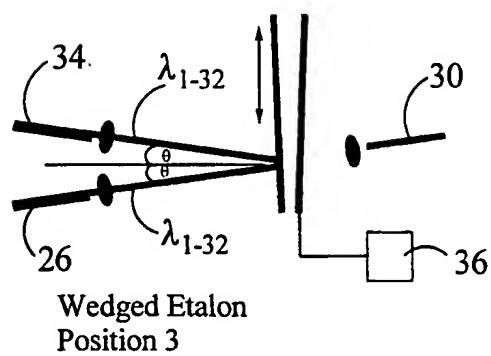


Fig. 5C

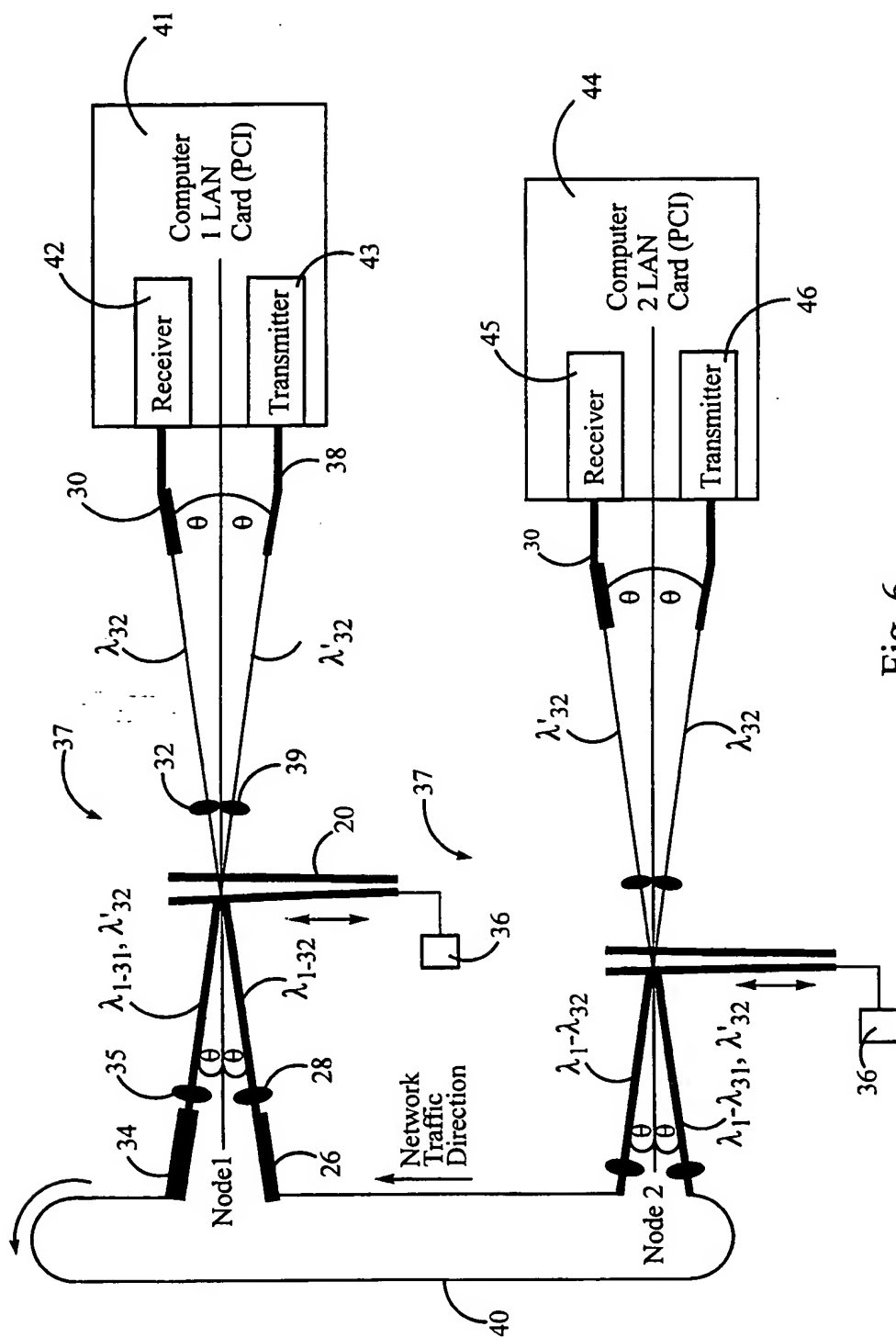


Fig. 6

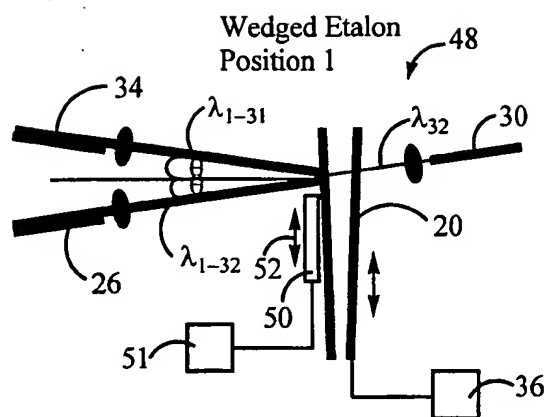


Fig. 7A

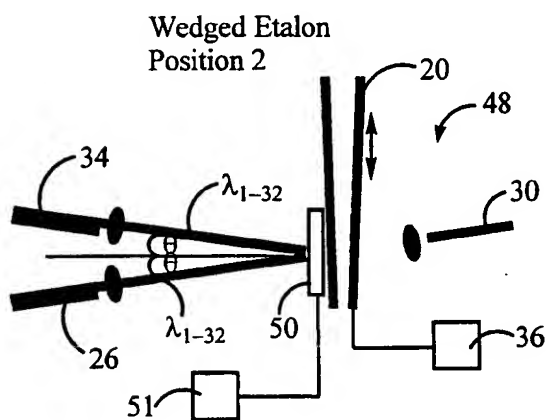


Fig. 7B

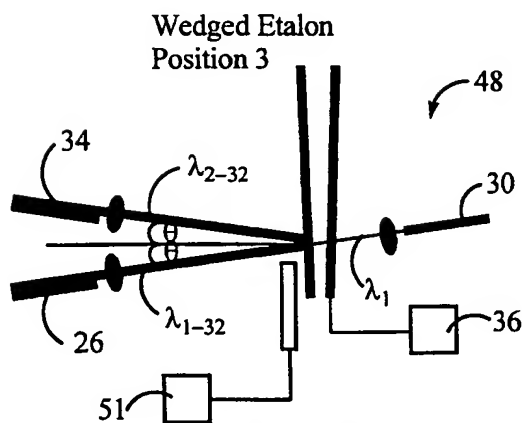


Fig. 7C

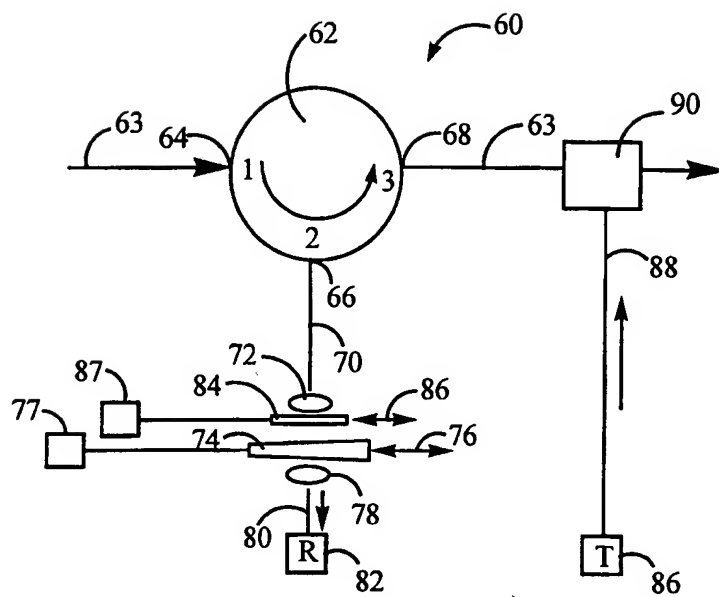


Fig. 8

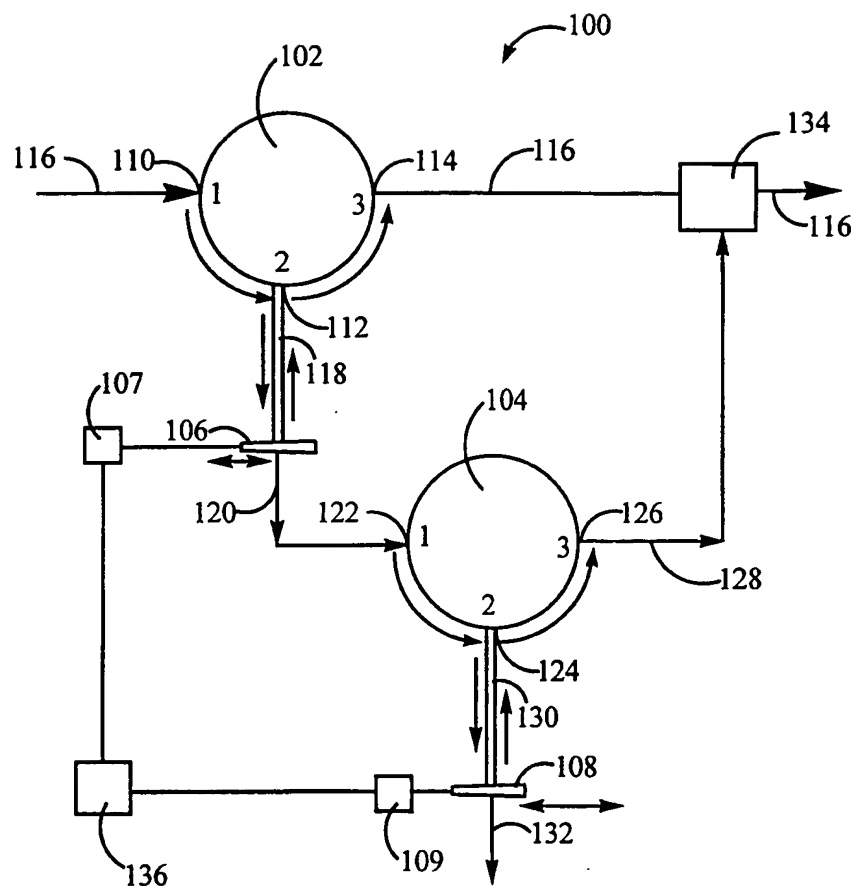


Fig. 9

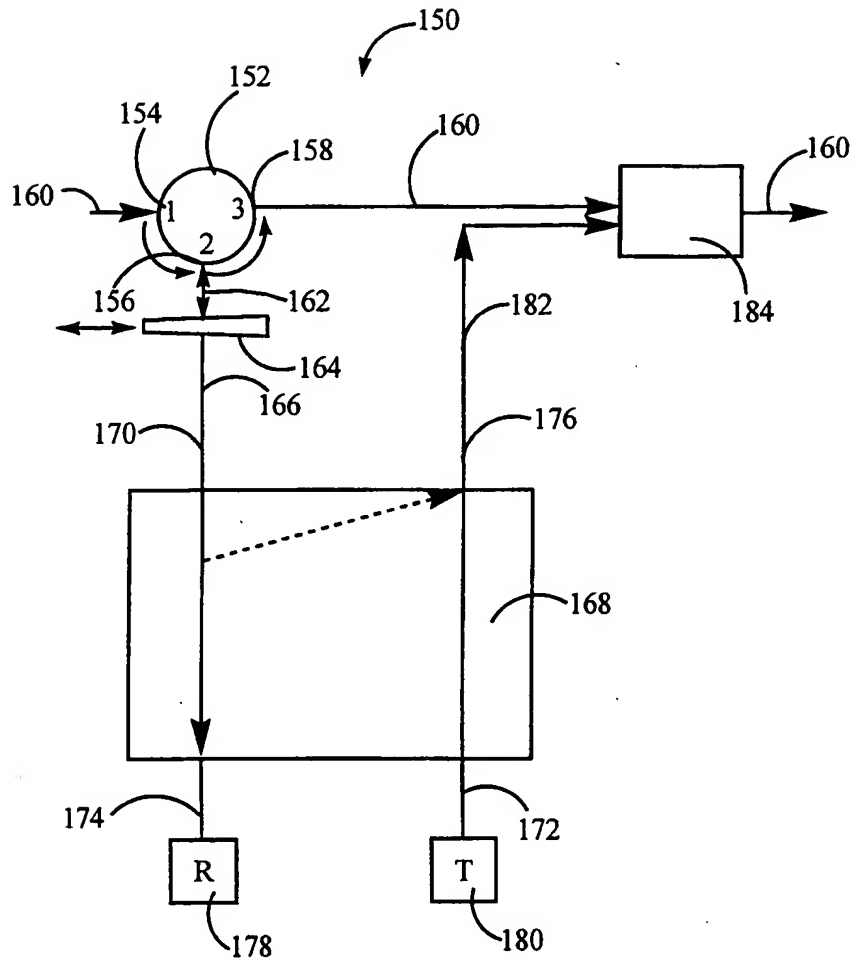


Fig. 10